Spatial and temporal variation in active layer thickness, Calypsostranda, Spitsbergen

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ABSTRACT: As part of wider investigations of the natural environment, the thickness and thaw rate of the active layer was studied annually from 1986–2002 in the Calypsostranda region, Spitsbergen. This coastal plain is sparsely vegetated and consists of a complex of raised marine terraces formed from Quaternary sands, gravels, tills and marine clay overlying Tertiary sandstone. The thickness of the active layer was measured in representative tundra geosystems. Analysis of the data showed wide variation in active layer thickness over relatively small distances.

1 INTRODUCTION

The thickness of the active layer in permafrost terrain varies from year to year in response to climatic variations. A continuous increase in active layer thickness, however, in the absence of changing ground cover or snow depth and duration, implies an increase in air temperature and may be treated as an indication of climatic change.

Studies of the dynamics of the active layer are incorporated into the scientific research programmes of many countries engaged in permafrost research. The CALM (Circumpolar Active Layer Monitoring) programme was created in order to collect and make available data from at least 117 sites, in both hemispheres and with the co-operation of 15 countries, including Poland (Brown et al. 2000).

Studies of the active layer on Spitsbergen (Svalbard Archipelago) have been included in scientific research expeditions by the Maria Curie-Skłodowska University in Lublin since 1986. A programme of complex studies of the geographical environment, involving various sciences, has been undertaken. Preliminary results of these studies have been published (e.g., Repelewska-Pękalowa and Gluza 1988, Repelewska-Pękalowa and Paszczyk 1990, Repelewska-Pękalowa, 1994).

Measurement of the active layer at Calypsostranda is linked to a broader research programme in the Bellsund region which aims at documenting changes which have taken place in the last 16 years. The extent of this research was the reason for its inclusion in the CALM network, as the second base on Spitsbergen, after Kapp Linné (Åkerman 1995). Results of measurements carried out in the summers of 1986–1993, 1995–1997 and 2000–2002 have been contributed to the CALM data-base (Brown et al. 2000).

In this paper, active layer dynamics and the geomorphological effects of active layer development are discussed.

2 STUDY AREA

The aim of our studies was to ascertain the magnitude and rate of the development of the active layer. Investigations were carried out in the north-west part of Wedel Jarlsberg Land on Spitsbergen (Fig. 1) in the Bellsund region, on the coastal plain of Calypsostranda.
The Calypsostranda plain is located on the western outskirts of the Recherche Fiord and is adjacent to the Renard and Scott glaciers. It constitutes a complex of raised marine terraces resulting from isostatic movements following deglaciation (Marcinkiewicz 1961, Landvik et al. 1988, Troitsky et al. 1979). This area is mainly composed of Pleistocene tills, sands, gravels and marine clays, covered by a series of Holocene colluvial and fluvioglacial covers, modified by periglacial processes. The bedrock is made up of Tertiary sandstones and mudstones with coal inserts (Flood et al. 1971, Pekala 1987, Dallman et al. 1990).

The largest area is covered by a terrace 20–30 m above sea level, divided by rivers characterized by glacial or nival regimes. The terrace is subject to washing out by melt-water and by deflation during the frequent periods of strong winds (Bartoszewski 1998, Pekala 1987, Swies 1988). Deflation tundra plant communities prevail on the raised marine terraces (Rzetkowska 1987, Swies 1988).

The development of the active layer is dependent on the ground surface temperature, which is itself dependent on the air temperature, snow depth and snow cover duration. The TDD (Thawing Degree Days) index can be determined from the daily mean temperature of the air. Data for Calypsostranda are shown in Table 1.

<table>
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<th>TDD</th>
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Table 1. Thawing Degree Days index for Calypsostranda.

The development of the active layer is dependent on the ground surface temperature, which is itself dependent on the air temperature, snow depth and snow cover duration. The TDD (Thawing Degree Days) index can be determined from the daily mean temperature of the air. Data for Calypsostranda are shown in Table 1.

The average value at Calypsostranda for 1990-2001 was 324.3. A similar result was obtained by Åkerman for Kapp Linné on Spitsbergen (Brown et al. 2000). For comparison, Siberian areas with continental climates have coefficients of about 900–1000 (Brown et al. 2000).

3 METHODS

Measurements of the thickness of the active layer were taken at points representing various typical tundra geo-complexes. These points were located in an area of west-east and north-south transects, on the flat surface of Calypsostranda as well as on slopes with various orientations (north, south, east, west and north-east). The probing method was usually used. (“A 1 cm diameter graduated steel rod is inserted into the ground to the depth of resistance, to determine the depth of thaw” (Brown et al. 2000)). Depending on logistics, measurements were taken several times over the summer and especially when maximum thaw was attained in the second half of August. At chosen points, measurements were taken using Danilin’s frostmeter. Danilins’ soil frostmeter is designed to measure the depth to which the soil is frozen and this is the equipment used by meteorological services. “The sensor of this instrument consists of rubber hose filled with water and closed on both ends. This rubber hose is attached to the end of a round wooden rod, which is inserted into a vinylplastic tube sunk into the ground. The depth to which the ground is frozen or thawed may be determined by feeling for the frozen water in the rubber hose (after having removed it from the tube) and locating the top of this ice column on the scale found on the rose” (Meterological instruments v/o “Mashproborintorg” SSSR, Moskva, Chapter: Instruments for measuring the temperature of the air and soil, pp. 64–66).

As a supplement to probing, measurements of ground temperature were taken, first at several points (Gluza et al. 1988), but later in the central part of the area, close to the expedition’s seasonal meteorological station in Calypsobyen.

4 DEVELOPMENT OF THE ACTIVE LAYER

Since meteorological and geological conditions are uniform in the study area, other factors must be responsible for variation in summer thaw depths. Measurements were made at dry sites, sites with stagnant water or flowing water, sites with a thin vegetation cover and sites with typical tundra vegetation. Maximum thaw depths for 1986–2001 are shown in Table 2.

Table 2 demonstrates that the role of running water on the surface material and the surface is important, and results in the conduction of heat (point 4) or in an insulatory role for stagnant water (point 5). Where water served as a heat conductor, maximum thaw reached 196 cm (point 4 in 1993). The shallowest depths of thaw, in the range of 45–83 cm, were observed where stagnant water played an insulatory role.

Slope orientation also played a significant role. On south-facing slopes, the thickness of the active layer reached 180 cm, whereas the maximum thaw depth recorded on north-facing slopes was 150 cm. High values were also found on east-facing slopes due to exposure to a greater number of föhn-type winds, which bring masses of air which have warmed adiabatically whilst crossing the mountain barriers.

It should be stressed that in the study area, great variations in the thickness of the active layer were noted in places which were located close to each other.
In order to define the development and rate of ground thaw, daily measurements of the thickness of the active layer were taken in the summer season of 1996, using Danilin’s frostmeter. The frostmeters were installed at three points: on a raised marine terrace 20 m above sea level, on the beach and on a slope facing east (see Fig. 1). Measurements taken in July and August 1996 indicate that while there was a general tendency to increasing thaw depths, both thawing and refreezing took place (Fig. 2). This reflected the balance between penetration of heat from the ground surface and heat conduction into the cold permafrost below.

Changes in thickness are obviously linked with air temperature, but also with rain/snowfall and with föhn-type winds. It was ascertained that the reaction of the active layer to changes of air temperature was delayed by 24 hours. The rate of change was 1 to 25 cm per day. Large changes in amplitude were linked to a decrease in temperature after a period of warm föhn winds.

### 6 GEOMORPHOLOGICAL EFFECTS OF THE DEVELOPMENT OF THE ACTIVE LAYER

Geomorphological process investigations also started in 1986, using geomorphological mapping and hydrochemical methods.

Variations in the activity of geomorphological processes were associated with climatic and orographic factors and were affected by the presence of erodible surficial deposits, a lack of thick vegetation, humidity and the changing thickness of the active layer. The main processes are ablation, solifluction, aeolian and niveo-aeolian processes, erosion and thermoerosion, as well as mass movements.

Rapid snowmelt occurs under the present climate, and given the lack of thick vegetation, this favours the development of ablational processes and colluviation, with erosion on the higher parts of slopes. Ice wedges, which are common on the surface of Calypsostranda, constitute a focus for drainage of meltwater and

### Table 2. Maximum thaw depths at Calypsostranda (cm).

<table>
<thead>
<tr>
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<th>Point</th>
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<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
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Points 1–5 are located on north-south and west-east transects: 1 – a flat marine terrace, built of sands and gravel; 2 – patterned ground with running water within sandy-gravelly surface materials, mosses on the peat layer; 3 – patterned ground, running water in the surficial materials, formed of sands and coarse gravels, absence of vegetation; 4 – small stream, between points 2 and 3, gravelly sandy cover, absence of vegetation; 5 – peat within a shallow lake. Slopes with various orientations: E1 – Northerly, E2 – Southerly, F – Easterly, G – Westerly.
rainwater, and are subjected to erosion and thermoerosion (Repelew ska-Pe kalowa & Pe kala 1993) (Fig. 3).

A system of cracks and ice wedges transforms itself into a network of erosional gullies with slopes later modified by solifluction. Where thick vegetation is present, hollows are formed and new gullies develop above thermal contraction cracks and ice wedges, which link up to form classic polygonal thermokarst terrain (Fig. 4).

A greater concentration of water in the active layer in the small and shallow bowl-like valleys (dells) situated on south- and south-west facing slopes, where there is a deeper thawing, accelerates solifluction processes. Mudflows and other landslides commonly develop (Fig. 5).

Marine deposits, and the colluvial deposits which cover them, have created a 2–4 m high marine terrace. The terrace surface is dry during the summer, because the permafrost table reaches a depth of up to 2 m. This is an area of active aeolian processes affected by the föhn winds coming from the east.

Deeper thawing and winter refreezing favour the development of patterned grounds, especially of sorted stone circles on flat areas (Fig. 6), and stone garlands on slopes. Palsas covered by peat vegetation are subject to degradation as are hydrolaccoliths formed in the zone of water accumulation in the covers of alluvial fans.

7 CONCLUSIONS

Thaw depth measurements undertaken over more than 1 year on the Calypsostranda plain, show wide variation in the active layer thickness over relatively small distances.

This fact, together with an obvious influence of local factors on the extent and rate of thawing, should be taken into account when producing general schemes and models of the development of the active layers of permafrost, which are needed for scientific as well as applied purposes.

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